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Title: Assessment of Costing Assumptions in Multi-Strata Evaluations of Partitioning and Transmutation for Advanced Accelerator Applications

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Background

In June, 2001, John Herczeg, AAA Program Manager, identified objectives for the AAA "Multi-Strata Approaches" Study. Nuclear waste management in the United States will be evaluated based upon current and potential disposal/treatment options. An integral portion of this evaluation is the development of models representative of the various aspects of each disposal/treatment option.

These relevant models will incorporate the goals of the program. These goals according to the memo issued by John Herczeg are:

- Improve the long term public safety by reducing the radiotoxicity and potential radiological dose from spent nuclear fuel
- Reduce the proliferation risk from spent nuclear fuel
- Provide benefit to the repository program by reducing the volume and thermal load from spent nuclear fuel
- Improve the prospects for nuclear power by providing a viable and economically feasible waste management strategy.

In addition to these goals, the proposed methodology entails identification of initial approaches based on the literature and existing work by international and domestic communities. Currently, a model developed for the OECD is being examined for use in this project. This model, developed by R. A. Krakowski (Krakowski, 2001), incorporates proliferation concerns, mass flow, and economic outcomes for a given scenario.

Integration of this model for AAA system studies satisfies the goals and methodology set forth in the Charter for the AAA "Multi-Strata Approaches" Study.

Discussion of OECD model

The "Top-Level" Costing of Advanced Nuclear Fuel was developed by R.A. Krakowski at the Paul Scherrer Institute for the Organization for Economic Cooperation and Development (OECD). The model provides a top-level analysis of economics, waste production, and proliferation risks for several fuel cycle scenarios. The five scenarios are normalized with respect to a current once-through LWR cycle.

Various Partitioning and Transmutation (P & T) technologies are used in the model. Partitioning technologies used include PUREX, UREX, and Pyrochemical separations. Transmutation technologies are Light Water Reactors (LWRs), Fast Reactors (FRs), and Accelerator-Driven Systems (ADSs). The five scenarios are:

1. LWR once through option (LWROT)
2. Pu burning in LWR/MOX, followed by final Pu burning in FR/MOX with MAs to repository

3. TRU burning from LWROT in FR (metal), or TRU burning from LWROT in ADS (metal fuel), or TRU burning from LWROT and LWR/MOX in ADS (metal fuel)
4. Pu burning in LWROT – LWR/MOX – FR/MOX with MA extracted in aqueous processing and burned in ADS (metal fuel)
5. Fast Breeder Reactor (FBR)

This model provides an overall view of each of the scenarios. The mass flow within the model incorporates mass flow to the repository and fuel/fission products through each stage. Based upon the calculated mass flows, component annual charges (AC) are calculated using a unit cost (UC) and mass flow rate (MR) as follows:

$$AC_{process}\ (\$/yr) = UC_{process}\ (\$/kg) * MR_{process}\ (kg/yr)$$

Summing these annual charges, a total cost of electricity (COE) can be calculated using the total net annual electricity generated.

$$COE\ (mill/kWeh) = AC_{total}\ (\$/yr)/[8{,}760\ (hr/yr) * P_{total}\ (kWe) * P_{availability}]$$

Where
AC_{total} = Total Annual Charges for one scenario
P_{total} = Total electricity generation for one scenario
$P_{availability}$ = Plant availability

Mass flow rates and power generation are both critical in the calculation of the COE, (used as an economic comparison index) however in this report we will focus on the assumptions associated with the ACs. Because this top-level approach to nuclear waste management option analysis is applicable to the AAA program, it is essential to examine to the cost data used. The costs used are examined in the nearly completed OECD Comparative Study of ADS and FR in Advanced Nuclear Fuel Cycles. In the *Cost Comparison* section, these costs and the costs required are discussed.

Application to Tier system

Currently, a "Tier" system is being used for systems organization in the AAA project. These Tiers are organized as follows:

1. LWROT (Commercial Reactor, base case)
2. Tier 1
    a. Separation (PUREX, UREX, pyro)
    b. Fuel Fabrication (MOX, NFF Zr, Pu TP, Pu/Np TP, TRU TP)
    c. Irradiation (LWRTSI, GCRTSI)
    d. Short Cooling Storage
    e. Recycle Separation
3. Tier 2
    a. Fuel Fabrication (OX, ZrN, Zr Metal)
    b. Irradiation (SADFSI, LMRFSI)

c. Short Cooling Storage
d. Recycle Separation
e. Recycle Fuel Fabrication

Upon examination of the scenarios incorporated in the Delta model and the Tier system, it can be seen that the Delta model is an accurate initial approach for AAA modeling. The model used for AAA will incorporate 13 scenarios.

The AAA Tier system is based upon several assumptions. These assumptions are given in the Advanced Nuclear Transformation Technology (ANTT) Subcommittee report from April 18-19, 2001 (Richter, 2001). The report established the goals outlined in Herczeg's memo of June, 2001. The attainment of the goals is based upon the assumption of a steady-state U.S. Nuclear future, that is, future reactors are operating with spent fuel in equilibrium. Results should be presented on a per 100 GWe basis with the base cast LWROT. The OECD study should be used as a starting point for the AAA model.

OECD Economics

Based upon the call for the use of the OECD model in the AAA Tier system, the economic data must be assessed or obtained for specific scenarios in the AAA system. Economic factors used in the OECD report should be used as indicators of economic data needed for AAA. Because AAA is using 13 scenarios, more information is required. The following tables are presented to compare OECD economic assumptions with AAA economics. OECD values are listed with a reference unit cost in 2000 dollars with the applicable source. The OECD report utilizes 3 values: low, nominal, and high. R. A. Krakowski and AAA staff, however, feel it is best to use a nominal value and an associated sigma. The OECD economic model presents a cost trend through the use of these ranges rather than a best estimate. The nominal value is a "best available cost figure" with the high and low values derived from expert judgment. Therefore, for the purpose of this comparison, nominal values will be used.

Because the 5 scenarios used in the OECD model and the 13 scenarios addressed by AAA differ, different pieces of economic data will be required for application to the AAA program. While the basic model framework is still applicable, economic data representative of the High Temperature Gas-cooled Reactor (HTGR) scenarios (13 parallel scenarios in which the HTGR replaces the LWR), alternative fuels, and recycled fuel fabrication are necessary. This data, while partially presented in this document, must be procured due to lack of industrial experience information.

Cost Comparison

In the following tables, OECD costs as well as costs provided for comparison are presented. Several items in the table do not have associated costs due to the fact that they are representative of new technologies and cost data is currently unavailable.

Table I Unit costs for Mining and Milling Conversion Enrichment

Cost Component	OECD Unit Cost	Reference Unit Cost	Source
	Nominal Value	*Nominal Value*	
Uranium mining and milling ($/kgU)	30	40	OECD/NEA -94
Uranium conversion from U_3O_8 to UF_6 ($/kgU)	5	5	OECD/NEA -94
Uranium enrichment ($/SWU)	80	125	Choi-98
Uranium conversion from irradiated UO_2 to UF_6 ($/kgU)	24		

Table II Unit Costs For Commercial Reactors

Cost Component	OECD Unit cost	Reference Unit Cost	Source
	Nominal Value	*Nominal Value*	
ALWR			
Plant Factor	0.855		
Fixed Charge Rate (1/yr)	0.1		
O&M Annual Charge For Reactor Operation (%)	3	4	NAP-96
Unit Total Capital Cost ($/We)	1.3	1.6	NAP-96
Fresh Fuel Storage ($/kgHM/yr)	30	*Facility Dependent*	
Unit Cost of Cooling Storage ($/kg/yr)	60		
Fuel Fabrication Unit Costs ($/kgHM)	250	230	OECD/NEA -94
O&M Annual Charge For Fuel Fabrication Facility (%)		20	DOE-99
Nominal Transportation Cost ($/kg) [c]	30	40	OECD/NEA -94
Repository Cost for High-Level Waste ($/kg)	200	130 (U)	OECD/NEA -94
AHTGR			
Plant Factor			
Fixed Charge Rate (1/yr)		0.1	Kadak-98
O&M Annual Charge For Reactor Operation (%)		2	Kadak-98
Unit Total Capital Cost ($/We)		1.8	Kadak-98
Fresh Fuel Storage ($/kgHM/yr)		*Facility Dependent*	
Unit Cost of Cooling Storage ($/kg/yr)			
Fuel Fabrication Unit Costs ($/kgHM)		420	ANL-91
O&M Annual Charge For Fuel Fabrication Facility (%)			
Nominal Transportation Cost ($/kg) [c]		40	OECD/NEA -94
Repository Cost for High-Level Waste ($/kg)		130 (U)	OECD/NEA -94

Table III Unit Costs For Tier I LWR Thermal Spectrum Irradiators

Cost Component	OECD Unit cost	Reference Unit Cost	Source
	Nominal Value	*Nominal Value*	
Plant Factor	0.855		
Fixed Charge Rate (1/yr)	0.1		
O&M Annual Charge For Reactor Operation (%)	3	4	NAP-96
Unit Total Capital Cost ($/We)	1.3	1.6	NAP-96
Separation costs ($/kgHM)	800		
O&M Annual Charge For Separation Facility (%)	10	6	NAP-96
Fresh Fuel Storage ($/kgHM/yr)	30	*Facility dependent*	
Unit Cost of Cooling Storage ($/kg/yr)	60		
Nominal Transportation Cost ($/kg)	30	40	OECD/NEA -94
Repository Cost for High-Level Waste ($/kg)	200	130 (U)	OECD/NEA -94
MOX Fuel Fabrication Unit Costs ($/kgHM)		660	NAP-96
MOX O&M Annual Charge For Fuel Fab. Facility (%)		20	DOE - 99
MOX Separation costs ($/kgHM)	800	700	OECD/NEA -94
MOX O&M Annual Charge For Separation Facility (%)	10	6	NAP-96
Recycled MOX Fuel Fabrication Unit Costs ($/kgHM)	1100	1650	Ikemoto-99
Recycled MOX O&M Annual Charge For Fuel Fab. Facility (%)	15	20	DOE-99
NFF Zr Fuel Fabrication Unit Costs ($/kgHM)			
NFF Zr O&M Annual Charge For Fuel Fab. Facility (%)			
NFF Zr Separation costs ($/kgHM)			
NFF Zr O&M Annual Charge For Sep. Facility (%)			
Recycled NFF Zr Fuel Fabrication Unit Costs ($/kgHM)			
Recycled NFF Zr O&M Annual Charge For Fuel Fab. Facility (%)			

Table IV Unit Costs For Tier-I HTGR Thermal Spectrum Irradiators

Cost Component	OECD Unit cost	Reference Unit Cost	Source
	Nominal Value	*Nominal Value*	
Plant Factor			
Fixed Charge Rate (1/yr)		0.1	Kadak-98
O&M Annual Charge For Reactor Operation (%)		2	Kadak-98
Unit Total Capital Cost ($/We)		1.8	Kadak-98
Separation costs ($/kgHM)	800		
O&M Annual Charge For Separation Facility (%)	10		
Fresh Fuel Storage ($/kgHM/yr)		*Facility dependent*	
Unit Cost of Cooling Storage ($/kg/yr)			
Nominal Transportation Cost ($/kg)		40	OECD/NEA -94
Repository Cost for High-Level Waste ($/kg)		130 (U)	OECD/NEA -94
Pu TP Fuel Fabrication Unit Costs ($/kgHM)			
Pu TP O&M Annual Charge For Fuel Fab.Facility (%)			
Pu TP Separation costs ($/kgHM)			
Pu TP O&M Annual Charge For Separation Facility (%)			
Recycled Pu TP Fuel Fabrication Unit Costs ($/kgHM)			
Recycled Pu TP O&M Annual Charge For Fuel Fab.Facility (%)			
Pu+Np TP Fuel Fabrication Unit Costs ($/kgHM)			
Pu+Np TP O&M Annual Charge For Fuel Fab. Facility (%)			
Pu+Np TP Separation costs ($/kgHM)			
Pu+Np TP O&M Annual Charge For Sep. Facility (%)			
Recycled Pu+Np TP Fuel Fabrication Unit Costs ($/kgHM)			
Recycled Pu+Np TP O&M Annual Charge For Fuel Fab. Facility (%)			
TRU TP Fuel Fabrication Unit Costs ($/kgHM)			
TRU TP O&M Annual Charge For Fuel			

Fab.Facility (%)			
TRU TP Separation costs ($/kgHM)			
TRU TP O&M Annual Charge For Separation Facility (%)			
Recycled TRU TP Fuel Fabrication Unit Costs ($/kgHM)			
Recycled TRU TP O&M Annual Charge For Fuel Fab.Facility (%)			

Table V Unit Costs For Tier-II SAD Fast Spectrum Irradiators

Cost Component	OECD Unit cost	Reference Unit Cost	Source
	Nominal Value	*Nominal Value*	
Plant Factor	0.7957		
Fixed Charge Rate (1/yr)	0.1		
O&M Annual Charge For Accelerator Operation	6	3.5	DOE-99
Unit Total Capital Cost ($/We)	2.9	2.25	DOE-99
Fresh Fuel Storage ($/kgHM/yr)	30	*Facility dependent*	
Unit Cost of Cooling Storage ($/kg/yr)	60		
Nominal Transportation Cost ($/kg)	30	40	OECD/NEA -94
Repository Cost for High-Level Waste ($/kg)	200	130 (U)	OECD/NEA -94
OX Fuel Fabrication Unit Costs ($/kgHM)			
OX O&M Annual Charge For Fuel Fab. Facility (%)			
OX Separation costs ($/kgHM)			
OX O&M Annual Charge For Separation Facility (%)			
Recycled OX Fuel Fabrication Unit Costs ($/kgHM)			
Recycled OX O&M Annual Charge For Fuel Fab. Facility (%)			
ZrN Fuel Fabrication Unit Costs ($/kgHM)		3600	OECD/NEA -94
ZrN O&M Annual Charge For Fuel Fab. Facility (%)		20	DOE-99
ZrN Separation costs ($/kgHM)		4220	OECD/NEA -94
ZrN O&M Annual Charge For Separation Facility (%)		6	NAP-96
Recycled ZrN Fuel Fabrication Unit Costs ($/kgHM)			
Recycled ZrN O&M Annual Charge For Fuel Fab. Facility (%)			
Zr Fuel Fabrication Unit Costs ($/kgHM)			
Zr O&M Annual Charge For Fuel Fab. Facility (%)		20	DOE-99
Zr Separation costs ($/kgHM)	800		

Zr O&M Annual Charge For Separation Facility (%)	10		
Recycled Zr Fuel Fabrication Unit Costs ($/kgHM)	11700		
Recycled Zr O&M Annual Charge For Fuel Fab. Facility (%)	15	20	DOE-99

Table VI Unit Costs For Tier-II LMR Fast Spectrum Irradiators

Cost Component	OECD Unit cost	Reference Unit Cost	Source
	Nominal Value	*Nominal Value*	
Plant Factor	0.8493		
Fixed Charge Rate (1/yr)	0.1		
O&M Annual Charge For Reactor Operation (%)	3	4	NAP-96
Unit Total Capital Cost ($/We)	1.95	1.9	NAP-96
Nominal Transportation Cost ($/kg)	30	40	OECD/NEA -94
Repository Cost for High-Level Waste ($/kg)	200	130 (U)	OECD/NEA -94
Fresh Fuel Storage ($/kgHM/yr)	30	*Facility dependent*	
Unit Cost of Cooling Storage ($/kg/yr)	60		
Fuel Fabrication Unit Costs ($/kgHM)		1000	Westinghouse-93
O&M Annual Charge For Fuel Fabrication Facility (%)		20	OECD/NEA -94
Separation costs ($/kgHM)	1230	2000	JNC-99
O&M Annual Charge For Separation Facility (%)	10	6	NAP-96
Recycled Fuel Fabrication Unit Costs ($/kgHM)	1700	1650	Ikemoto-99
O&M Annual Charge For Recycled Fuel Fabrication Facility (%)	15	20	DOE-99

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